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Recent Orthodontic Advancements: A Systematic Review

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ABSTRACT

Background: The year 2023 has witnessed unprecedented advancements in orthodontic treatments, offering patients an enhanced level of comfort, efficiency, and effectiveness in dental care. This systematic review aims to identify the recent developments in the field of orthodontics and discuss their performance about clinical application.

Methods: The literature for this paper was identified and selected by performing a thorough search in the electronic databases like PubMed, Medline, Embase, Cochrane, Google Scholar, Scopus, Web of Science, published over the past five years. Literature reviews, systematic reviews, meta-analyses from January 2019– December 2023 were included in the study. Recent original articles within the past five years related to orthodontic advancements were also included in the study. After applying inclusion and exclusion criteria, 26 articles were scrutinized, studied and then critically analyzed. Quality analysis was performed using QUADAS-2.

Results: This study reveals that technological advancement and research in the field of orthodontics is getting pace. The field of orthodontics has embraced state-of-the-art technology, including digital orthodontics, customized clear aligners, accelerated treatment options, AI and robotic wire bending, to revolutionize smiles and improve oral health.

Conclusion: As technological advancements persist in the trajectory; one can foresee imminent and revolutionary breakthroughs in the years ahead. This study will help and guide orthodontists to enhance their treatment strategies by keeping pace with the recent advancements in the field.

Keywords: Recent Advances, Digital Orthodontics, Precision Orthodontics, AI Orthodontics, Zirconia Brackets.

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INTRODUCTION

The progress witnessed in the field of orthodontics throughout the preceding three decades can be attributed to the impetus provided by technological innovations, particularly in the realms of volumetric and surface 3D imaging, as well as the advent of sophisticated digital software. These technological strides have facilitated the extraction of intricate diagnostic information, enhanced the precision in tailoring individualized treatment plans, and enabled the production of bespoke orthodontic appliances[1].

In addition, artificial intelligence (AI) has the potential to simulate human-like intelligence in machines, allowing them to make logical and critical decisions. The field of orthodontics has seen significant growth in the use of AI, and it is now a leading area of research[2]. The landscape of orthodontic care has been reshaped by key innovations in research and technology, and in this article, we will explore some of these innovations that have transformed the field of orthodontics over the past few years.

The article underscores the profound impact of technological innovations, particularly in artificial intelligence, dental robotics, 3D imaging, and digital software. These technologies have revolutionized diagnostic accuracy, treatment planning, and the creation of customized orthodontic appliances. By detailing these advancements, the article aims to show how research has refined and enhanced orthodontic practices. This focus will allow readers to understand the current state of orthodontic advancements and their practical implications. Furthermore, many orthodontists face uncertainty when considering new equipment for their clinics. This article also aims to address this challenge by providing a thorough update on the latest innovations in orthodontics, thereby equipping practitioners with the knowledge needed to make informed decisions about incorporating advanced technologies into their practice.

METHODS

Resource's Selection

This systematic review was carried out after referring the guidelines for preferred reporting items for Systematic reviews and Meta-analyses extension for Diagnostic Test Accuracy(PRISMA-DTA)[3]. The literature for this paper was identified and selected by performing a thorough search in electronic data bases like PubMed, Medline, Cochrane, Google scholar, Scopus, and Web of science, published over the past five years (Jauary 2019–December 2023) by using keywords such as "Recent Advances in Orthodontics," "Digital Orthodontics," "Customized appliances," "Aligners," "Precision Orthodontics," "Robotics in Orthodontics," "Zirconia brackets," "AI in Orthodontics," and "Future Orthodontics" were employed. Full-length articles were obtained through a comprehensive approach involving electronic database searches Literature reviews, systematic reviews, and meta-analyses from January 2019– December 2023 were included in the study. Recent original articles within the past five years related to orthodontic advancements were also included in the study. The acquisition of relevant data for this review occurred in two distinct stages. Initially, articles were chosen based on the alignment of their titles and abstracts with our research topic. The preliminary search yielded 400 articles that sufficiently matched the paper's objectives. After identifying and eliminating duplicates, 130 articles were excluded, leaving us with 270 articles for the second stage of selection. Subsequently, a refined criterion was applied to further narrow down the selection process which is explained in the inclusion criteria. Finally, 26 articles were shortlisted for this review.

Inclusion / Exclusion Criteria

The articles included were mainly focused on recent advances related to the field of orthodontics. Systematic reviews, Literature reviews, meta-analyses and original articles from January 2019– December 2023 were included in the study. Articles related to the ongoing research which is not yet clinically implemented were also included in the study. Participants or population was not considered as it had no concern with the review. Original research was done in specialty clinics, academic institutions, or research laboratories. Our reference standard was that we finalized the most recent articles available through authentic databases in the past five years. Target condition was that we want to know the most recent and best advancement in the field of orthodontics to guide the treating doctors, so that they can benefit their patients. It was a qualitative review to know recent advances in Orthodontics so any measurable outcome was not set. The articles not related to any recent innovation, Case reports, articles that were unpublished and articles that were not written in English were excluded from the study. These criteria cut down the number of articles to 28. Further two articles were rejected because of reviewer disagreement, so a total number of 26 articles were included in the study.

Quality and Risk of Bias

A critical assessment was carried out for all the articles by following QUADAS-2 (Quality Assessment and Diagnostic Accuracy Tool) guidelines, a tool for quality assessment of the studies on diagnostic accuracy[4]. Two more articles were excluded due to disagreement from the authors. Eventually, this systematic review performed qualitative synthesis on 26 articles. PRISMA flowchart is shown in (Figure 1).

Data Extraction

The authors printed all 26 articles, studied them thoroughly and extracted the data manually from the selected articles collaboratively to reach a consensus on the information to be included. The years of these articles were taken in account to study the progress of recent trends that were developed and evolved over the past 5 years in dentistry. Duplicate studies and grey literature were already excluded, overlapping patient population was inapplicable in this review. Indeterminate data was ignored and only relevant information was included in the study about digital orthodontics, customized clear aligners, accelerated treatment options, AI, robotic wire bending and precision orthodontics.

RESULTS

This systematic review looked at 26 research articles and analyzed them. The literature analysis showed that most of the studies were conducted in the last 5 years. The trends suggest a gradual increase in research focusing on advancements in orthodontics, with notable contributions from Korean researchers.

The studies included in this review mainly centered around digital orthodontics, exploring the customization of orthodontic appliances. Recent research has also delved into materials for manufacturing Zirconia brackets. Another promising area is precision orthodontics, which has seen significant progress. Artificial Intelligence (AI) has played a substantial role in the field, with a noticeable increase in research over the past 5 years, indicating a growing interest and application of AI in orthodontics. Details of the studies that have been used in this review are listed in Table I along with year of publication, author names, and objectives.

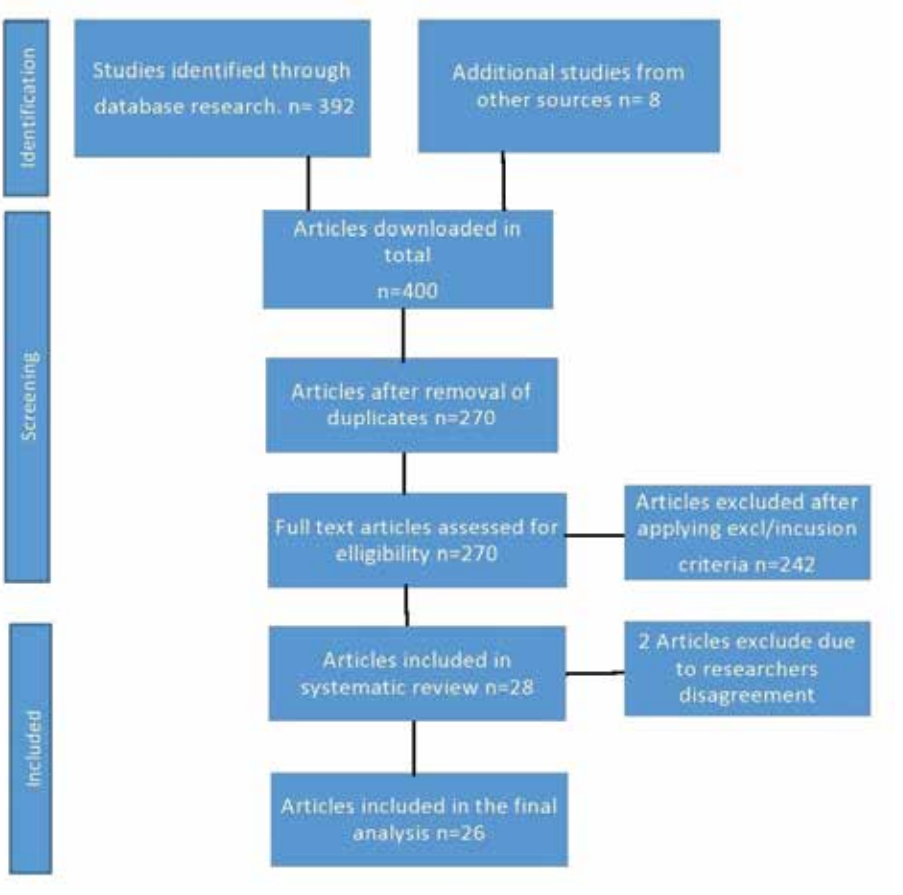

Figure 1: PRISMA Flow Diagram

PRISMA: Preferred Reporting Items for Systematic Reviews and Meta-Analyses.

Table I: List of Articles used in Systematic Review

Author	Objectives	Data Extraction Method
Panayi et al., 2023 [7]	To give knowledge about customized brackets.	Manually by concensus of reviewers.
Wang et al., 2023 [9]	To compare palatal dimensions and molar inclinations after Invisalign First System (IFS) to Slow Maxillary Expansion and Controls.	Manually by concensus of reviewers
Bichu et al., 2023 [11]	To give knowledge about advances in orthodontic clear aligner materials.	Manually by concensus of reviewers
Koenig et al., 2022 [13]	To compare the dimensional accuracy between direct-printed and thermoformed aligners.	Manually by concensus of reviewers
Xue et al., 2021 [15]	To evaluate the accuracy of invivo bracket placement using a computer-aided design and computer-aided manufacturing-guided bonding device.	Manually by concensus of reviewers
Lo et al., 2021 [18]	To use augmented Reality Technology for Orthodontic Bracket Positioning.	Manually by concensus of reviewers
Park et al., 2023 [25]	To analyze the dimensional accuracy, mechanical property, and optical stability of zirconia orthodontic bracket according to yttria proportions.	Manually by concensus of reviewers
Zang et al., 2023 [28]	To compare the shear rebond strength of zirconia brackets treated with different Er:YAG laser energies.	Manually by concensus of reviewers
Panayi et al., 2022 [24]	In-house three-dimensional designing and printing customized brackets	Manually by concensus of reviewers
Pekkan et al., 2020 [27]	To investigate factors affecting the translucency of monolithic zirconia ceramics.	Manually by concensus of reviewers
Bichu et al., 2021 [29]	To study the applications of AI and machine learning in orthodontics.	Manually by concensus of reviewers
Ahmed et al., 2023 [30]	To review the use of AI in relation to clinical decision making.	Manually by concensus of reviewers
Mathew et al., [33]	To analyze Neural networks for classification of cervical vertebrae maturation.	Manually by concensus of reviewers
Zhou et al., 2021 [35]	To develop an AI System for the Automatic Evaluation of	Manually by concensus of reviewers

Mohammad-Rahimi et al., 2022 [37]	To use deep learning to classify cervical vertebral maturation stages.	Manually by concensus of reviewers
Kwon et al., 2021 [38]	Probabilistic Approach for the Localization of Cephalometric Landmarks.	Manually by concensus of reviewers
Kim et al., 2021 [41]	Automatic Cephalometric Landmark Identification System Based on CNN.	Manually by concensus of reviewers
Takahashi et al., 2023 [42]	Cephalometric landmark detection without X-rays combining coordinate regression and heatmap regression.	Manually by concensus of reviewers
Real et al., 2022 [45]	Use of automated artificial intelligence to predict the need for orthodontic extractions.	Manually by consensus of reviewers
Miranda et al., 2023 [46]	Using AI to classify alveolar bone defects in cleft patients.	Manually by consensus of reviewers
Strunga et al., 2023 [47]	Using AI in the Course and Retention of Orthodontic Treatment.	Manually by concensus of reviewers
Adel et al., 2021 [51]	To study Robotic Applications in Orthodontics.	Manually by concensus of reviewers
Li et al., 2023 [53]	To study clinical application of robots in dentistry.	Manually by concensus of reviewers
Yang et al., 2020 [55]	To study Multiomics Systems Biology to Dissect Complex Diseases.	Manually by concensus of reviewers
Kreitmaier et al., 2023 [56]	To study multi-omics integration in complex disease primary tissues.	Manually by concensus of reviewers
Joshi et al., 2022 [58]	To study effect of IGF-1 TMJ injections enhance mandibular growth.	Manually by concensus of reviewers

DISCUSSION

DIGITAL ORTHODONTICS

The use of digital technology in orthodontics has transformed the field. The ability to digitize the oral cavity, use orthodontic computer-aided design (CAD) software for precise appliance creation or modification, and employ 3D printing has revolutionized the practice of orthodontics. The digitization process has redefined traditional orthodontic laboratories, moving them into the digital realm. Advances in digital software have allowed practitioners to gain a more comprehensive understanding of the oral cavity, enabling the development of precise and personalized treatment plans. Furthermore, the introduction of a streamlined, dust-free environment, made possible through scanners, computers, and printers, has allowed for the integration of this setup within orthodontic offices. This paradigm shift has led to the emergence of a new modality called in-office manufacturing, where the computer serves as the core of the digital laboratory, executing crucial functions such as design, editing, and the issuance of printing commands[5]. The advent of significant digital technological advancements in orthodontics has facilitated the utilization of "Vertical Axis Tilt," (VAT) technology printers for the production of a multitude of appliances, or alternatively, outsourcing to powder bed fusion printers for metal appliances. This transformative progress has spurred the concurrent evolution of other technologies. Initially confined to dental models, resin materials for 3D printing have expanded their applications to include occlusal splints,

individual dental bleaching (IDB) trays, orthodontic bands, rapid palatal expanders, and thermoformed and printed aligners. Conversely, in the past two years, compact 3D printers employing zirconia slurry, suitable for installation in dental offices, have become available in the market[6].

Customized Brackets

The debut of the initial orthodontic CAD software marks a pivotal advancement, enabling in-office design and printing of tailor-made brackets. Although commercial straight-wire brackets remain the norm for many orthodontists, customized brackets gain preference, particularly in lingual orthodontic procedures. The innovative CAD software, known as U brackets, facilitates on-site customization and printing of brackets, employing hybrid ceramic crown resin or zirconia slurry as materials of choice[6,7].

Directly printed Aligners

Clear aligners have surged in popularity as a subtle substitute for conventional braces. In 2023, technological strides have elevated clear aligner customization to match individual patients' distinct dental structures and treatment requirements. Improvements in software capabilities now enable the integration of CBCT scans into the CLIN Check program, which is particularly advantageous for extraction cases[8]. Additionally, advancements such as "Invisalign first" cater to mixed dentition malocclusions, while mandibular advancement options address Skeletal Class II corrections, illustrating the ongoing progress in clear aligner technology[9,10].

These developments aim to provide greater control over tooth movements. The current trend in aligner therapy involves the use of shape-memory polymers (SMPs) and direct 3D printing of the aligners[11,12,13]. SMPs are a type of intelligent material that can change their macroscopic shape in response to external stimuli such as thermal, electrical, or magnetic input. Early in vitro studies have shown promising outcomes using a thermal responsive SMP (shape-memory sheet (ClearX)) by Kline Europe GmbH, Düsseldorf, Germany, and Graphy material. The future of aligner materials will involve the use of these SMPs, also known as smart materials, that are capable of self-sensing, self-responsiveness, shape memory, self-repair, self-adaptability, and multi-functionality. These advancements will also enhance control over tooth movements in aligner therapy[9].

AUGMENTED REALITY (AR) IN ORTHODONTICS

Augmented reality (AR) is a technology that effectively merges virtual objects with the real world. An AR system is characterized by three key features: the integration of real and virtual objects, real-time interaction, and precise three-dimensional alignment of the virtual and real objects. This technology was first developed by Boeing in 1990. The use of AR in orthodontic treatment planning has improved patient understanding of their treatment journey by providing realistic visualizations of their post-treatment smile and demonstrating the step-by-step progress during the treatment process. This not only enhances patient communication but also motivates and engages patients throughout their orthodontic journey[14]. Recent research has investigated bracket positioning techniques, examining methods involving orthodontic surgical guides, positioning gauges, and 3D-printed guides[15,16,17]. Although digital orthodontics has introduced more efficient bracket positioning approaches, cost and accessibility remain significant challenges. To address this issue, a cutting-edge solution takes the form of an AR-assisted bracket navigation system. This system comprises two main technical modules: the Facial Axis of the Clinical Crown (FACC) detection module and the bracket bonding navigation module. The FACC module uses computer vision to analyze real-time intraoral camera images, generating dental features such as the complete contour and FACC of each tooth. Additionally, the bracket bonding navigation module superimposes the real-time image with preoperational planning-determined bracket bonding positions, facilitating a visualized execution of the plan[18].

ZIRCONIA BRACKETS

Recent advances in zirconia materials have resulted in the development of numerous zirconia variants, influenced by factors such as powder selection, sintering additives, heat treatment, and other processing considerations[19]. The primary phases of pure zirconia are monoclinic at room temperature, tetragonal above 1170 °C, and cubic above 2370 °C. While the monoclinic phase lacks mechanical strength, incorporating dopants like yttria into the starting powder is crucial for enhancing strength and fracture toughness[20-21-22]. Innovations aimed at achieving high-translucency partially stabilized zirconia have led to the development of higher yttria contents, notably at 4 mol% (4Y-YSZ) or 5 mol% (5Y-YSZ), which promotes a greater presence of the non-birefringent cubic phase. These advancements, driven by increased yttria concentrations, have significantly expanded the clinical applications of zirconia, particularly in the realm of aesthetics[15]. The increasing prominence of zirconia is evident in both research and the development of orthodontic brackets[23,24,25]. However, existing literature indicates a direct relationship between yttria concentration, translucency, and mechanical strength in zirconia restorations. Although an elevated yttria concentration enhances translucency by stabilizing the cubic phase, it may also lead to a reduction in mechanical strength[26,27]. In a recent study conducted by Park and Giap, zirconia brackets containing 3 to 5 mol% YSZ demonstrated

improved reliability in terms of dimensional accuracy and exhibited favorable optical stability. Notably, the 3Y-YSZ variant showcased significant potential as an advanced material for the fabrication of orthodontic brackets due to its advantageous mechanical properties[28].

USE OF ARTIFICIAL INTELLIGENCE (AI) IN ORTHODONTICS

Orthodontics has undergone significant transformations in recent years, driven by technological advancements. However, a new era is on the horizon, characterized by rapid evolution fueled by the promise and applications of artificial intelligence (AI) in orthodontics. A scoping review highlights the exponential growth of AI applications in various orthodontic domains, including diagnosis, treatment planning, landmark detection, growth assessment, and evaluation of treatment outcomes[29].

Growth Estimation

Precise timing is imperative in orthodontic diagnosis and treatment planning, with the assessment of an individual's growth serving as a crucial component. The CVM (cervical vertebral maturation) method, a reliable radiological approach involving the evaluation of growth-related changes in wrist bones or vertebral bodies, aids in determining skeletal age[30]. Recent advancements in artificial intelligence (AI) have introduced deep learning algorithms capable of accurately assessing radiographs, resembling the proficiency of a radiologist in evaluating skeletal maturity.[31] Although studies, such as the one conducted by Kok et al., indicate that artificial neural networks (ANN) can detect various stages of cervical vertebral growth, but the accuracy of this technique in detecting stage 5 is lower[32]. Another study found an accuracy rate ranged from 50% to more than 90%,with ANN models but challenges persist.[33]Guo and Han used convolutional neural networks (CNN) models to classify human age and found that the features extracted by machines may be different from that defined by humans.[34] Consequently, recent efforts have focused on automating the determination of skeletal age using AI. However, the results have exhibited heterogeneity, showing moderate agreement of 58% to 71% between the AI-predicted CVM stages and the human gold standard[35,36,37].

Cephalometry

Recent advances in automated techniques, specifically employing CNN, have significantly progressed cephalometric landmark detection [38]. These deep learning methods, outperforming those utilizing a random forest, have demonstrated exceptional outcomes[39,40,41].Inspired by visual biological recognition, CNNs have proven effective in precisely identifying cephalometric landmarks[40]. However, the existing studies predominantly rely on X-rays, posing concerns about direct patient exposure to X-ray radiation. Addressing this issue, Takahashi et al. proposed a model capable of detecting cephalometric landmarks solely using facial profile images, eliminating the need for X-rays. The model employs high-resolution representation learning to estimate landmark coordinates, refining them based on spatial relationships. Fully connected networks further enhance the accuracy of the estimated coordinates[42].

Treatment Planning Decisions

This AI advancement holds great potential for the future, driving discoveries across scientific disciplines by using powerful pattern-finding and prediction algorithms to assist researchers and clinicians[43]. Different machine learning algorithms contribute to processing data in various ways, such as unsupervised learning algorithms that can identify patterns in data with only a set of input data. For instance, principal component analysis, a common type of unsupervised learning algorithm, can be used to indicate the determining attributes of arch size, shape, and occlusal relations from a wide set of variables[44]. The integration of an automated machine learning system facilitates the development of orthodontic extraction prediction models. The enhancement of the analytical process through model and cephalometric data integration improves the accuracy of optimal extraction prediction models, achieving a notable accuracy rate of 93.9% for determining the necessity of extraction based on both model and radiographic data[45].

In a pioneering approach, Miranda and Choudhari introduced a novel classification algorithm to assess the severity of alveolar bone defects in CLP patients. This innovative algorithm utilizes 3D surface models and an AI-based algorithm to elucidate the decision-making process. By capturing 2D image snapshots from various angles and inputting them into a 2D Convolutional Neural Network, the AI algorithm extracts features from each viewpoint. Attention Layers are then employed to consolidate these features and explain the classification rationale.[46] In a separate study, Strunga and Urban found that AI can be a valuable tool for streamlining orthodontic treatment management, encompassing diagnosis to retention, benefiting both patients and clinicians. The ability of AI to significantly enhance patient engagement contributes to improved compliance[47].

AI Robotics in Orthodontics

Robotic systems have become indispensable tools in healthcare, aiding clinicians in surgeries and intricate interventions. Fueled by AI, these robots demonstrate remarkable precision in executing delicate tasks, ultimately leading to enhanced

outcomes for patients. Theodossy and Bamber pioneered the integration of robotic systems in orthognathic surgery planning, setting the stage for further advancements in this field[48]. Subsequently, Woo et al. developed a robotic system specifically designed to assist in orthognathic surgery. This system was seamlessly integrated into an image-guided virtual planning platform, ensuring the accurate translation of a preoperative virtual plan into the intraoperative phase of orthognathic surgery[49]. Extending the application of robotic technology, Zhang et al. engineered an arch wire-bending robotic system, utilizing the movement pattern of the MOTOMAN UP6 robot. Subsequent optimizations of parameters further refined the system's capabilities. These advancements underscore the transformative potential of robotic systems, powered by AI, in revolutionizing surgical procedures and improving patient outcomes[50]. Nanorobots/microrobots for acceleration of tooth movement and remote monitoring have already been introduced[51]. Furthermore, the AcceleDent robot, developed by OrthoAccel Technologies Inc. in Bellaire, TX, serves as a groundbreaking addition to orthodontic treatment. The innovative micro pulse vibration robotic system uses cyclic forces to accelerate teeth movement by enhancing bone remodeling, thus potentially reducing the discomfort associated with orthodontic procedures[52]. While these advancements have been made, it is important to recognize that current robots exhibit limited intelligence and a restricted range of functions, which renders them incapable of handling complex and dynamic oral diseases. Although diagnosis and treatment robots do not entirely alleviate the substantial clinical responsibilities of clinicians at present, the ongoing progress in artificial intelligence and related technologies is expected to address these limitations in the future[53].

PRECISION ORTHODONTICS

Precision medicine involves personalized diagnostic and therapeutic approaches that consider an individual's genetic, epigenetic, environmental, and lifestyle factors[54]. This concept extends to precision orthodontics, which leverages insights into the biological aspects of each individual, incorporating the patient's omics profile. This comprehensive understanding significantly informs treatment decisions, risk assessments, and therapy prognoses. Notably, precision orthodontics, along with certain medical domains like orthopedics, heavily relies on technology and advanced devices to deliver optimal care[55].

Application of Biologics and Multi-Omics in Precision Orthodontics

Multi-omics involves the high-throughput analysis of various biological molecules from cells, tissues, or organisms, offering a comprehensive readout for making associations and inferences about normal physiological or pathological processes. This technique covers genomics, transcriptomics, proteomics, epigenomics, metabolomics, and lipidomics, delving into genes, RNA, proteins, methylated DNA or chromosomal modifications, metabolites, and lipids, respectively. The integration of omics in healthcare is transforming disease classification, identifying therapeutic targets and precision drugs, and streamlining disease risk assessment and biomarker discovery[56].

The evolution of precision in orthodontics is still in its nascent stages and has primarily been explored in murine models[57]. Transcriptomic studies in mice have yielded insights into the molecular and cellular profiles of craniosynostosis, offering potential guidance for future research on tailored therapies. Additionally, murine models have demonstrated the capacity for enhanced condylar growth and improved orthodontic anchorage or retention through local injections of IGF-1 and osteoprotegerin, respectively[58].

Future Advancements

In the coming years, AI is poised to play a pivotal role in various domains, including clinical decision support, precision orthodontics, and customized appliance manufacturing. The convergence of AI with advancements in materials, omics, robotics, and 3D phenotyping holds the potential to transform orthodontics, ensuring optimized and predictable outcomes. Further investigation is essential to evaluate the efficacy and reliability of AI within real-world clinical environments.As AI technology progresses, its applications are likely to encompass increasingly complex scenarios, potentially leading to improved treatment outcomes. Therefore, the outlook for orthodontics in the broader context of dentistry remains highly optimistic.

CONCLUSION

The integration of virtual treatment simulations and AI-driven robotics represents a significant leap forward in orthodontics, enabling practitioners to offer an unprecedented level of individualized care. Despite the ethical dilemmas and challenges associated with these advancements, the trajectory for AI in orthodontics remains highly optimistic.

AI's evolving capabilities hold the promise of transforming clinical decision-making, refining image analysis, enhancing predictive modeling for risk assessment, and advancing precision orthodontics. As these technologies develop, they are set to elevate treatment outcomes, improve operational efficiency, and enrich patient experiences.

The ongoing advancements suggest that the field of orthodontics is on the cusp of a new era marked by technological sophistication and improved patient

care. The future of orthodontics, shaped by these innovations, looks exceedingly promising, underscoring the pivotal role that research and AI will play in advancing dental care.

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CONFLICT OF INTEREST
None to declare.

AUTHORS' CONTRIBUTIONS
SN: Conception of study, major work in article writing. **HGK;** Helped in literature search.
SA; Proofreading.

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